Uncertainty and Risk in Urban Infrastructure Systems

CEVE/STAT 313 – Spring 2013

MWF 10:00 AM – 10:50 AM, Mechanical Engineering Laboratory, Room 254

by

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Course objectives:

To introduce principles and methods that help quantifying the effects of uncertainty in the performance prediction of engineered infrastructure systems, and assist engineers and stakeholders with design, operation, and maintenance decision making. New concepts are presented with examples and exercise problems from different branches of engineering. Students will learn to apply quantitative risk analysis and modeling tools relevant to problems in modern infrastructure engineering and probabilistic decision making. The course emphasizes that the systematic treatment of uncertainty and risk quantification are essential for adequate engineering planning, design, operation, and decision making in the context of urban systems. It becomes clear that uncertainties are unavoidable but manageable with rational decision analyses.

Scope:

The course starts with a detailed study of the roles of probability in engineering and its impact on societal decision making, to then focus on computer-based methods in probability, the Bayesian approach to systematically combine real data with expert judgment, risk analysis tools, decision theory, optimization, and infrastructure safety. All mathematical concepts are developed in class and illustrated in the context of real engineering problems and phenomena.

Course calendar:

Week	Date	Lecture Topic	Suggested Reading
Introduction to uncertainty and risk assessment			
1	Jan. 7 – Jan. 11	Course overview, sample risk assessment studies, rational decision making, and the role of mathematical modeling.	[1] Ch. 1, [2] Ch. 1, [3] Ch. 1-2, [5] Ch. 1
Elements of probability			
2	Jan. 14 – Jan. 18	Random variables, distributions, conditional probability, total probability, and Bayes' formula.	[1] Ch. 2.3, 3.1, [2] Ch. 2, [3] Ch 3.1, [6] App. A

Descriptors of random variables and advanced probability distributions

3	Jan. 21 – Jan. 25	**Martin Luther King, Jr. Day (01/21/13)**, moments of random variables, expectation, characteristic functions, and functions of random variables, random trials, random occurrences, and summary of distributions.	[1] Ch. 3.1-3.2, 4, [2] Ch. 3-4, [3] Ch. 3.2-3.9

Decision Theory I

4	Jan. 28 – Feb. 1	Definitions, risk classifications, decision models, decision trees, decision criteria, and applications to risk assessment and management.	[2] Ch. 15, [3] Ch. 13.1-13.2, [4] Ch. 4

Decision Theory II

5	Feb. 4 – Feb. 8	**Exam I (02/06/13)**, decisions based on existing information and prior analyses, decisions based on additional information.	[2] Ch. 15, [3] Ch. 13.1-13.2, [4] Ch. 4

Decision Theory III

6	Feb. 11 – Feb. 15	Pre-posterior analyses, value of information, sensitivity of decisions to errors.	[2] Ch. 15, [3] Ch. 13.3, [4] Ch. 4

Utility Theory I

7	Feb. 18 – Feb. 22	Axioms of utility theory, utility functions, determination of utility values, decision maker preferences.	[3] Ch. 13.4-13.6, [4] Ch. 5, [5] Ch. 3

Spring break

8	Feb. 25 – Mar. 1	No class.	

Utility Theory II

9	Mar. 4 – Mar. 8	Utility function of monetary values and other variables, maximum expected utility, sensitivity of expected utility, assessment of probabilities.	[3] Ch. 13.4-13.6, [4] Ch. 5, [5] Ch. 4

Utility Theory III

10	Mar. 11 – Mar. 15	Decisions with multiple objectives, weighted decision analysis, multi-attribute utility theory.	[3] Ch. 13.4-13.6, [4] Ch. 5-6, [5] Ch. 9-10

Bayesian Approaches

11	Mar. 18 – Mar. 22	**Exam II (03/22/13)**, Bayesian discrete and continuous cases, Bayesian sampling theory.	[1] Ch. 9, [3] Ch. 4

Bayesian applications in sampling and estimation

12	Mar. 25 – Mar. 29	**Midterm recess (03/29/13)**, Bayesian estimation, regression, and correlation.	[1] Ch. 9, [3] Ch. 14

Limit and multivariate distributions

13	Apr. 1 – Apr. 5	Multivariate distributions, and distribution of extremes.	[1] Ch. 3.3 [2] Ch. 5

Empirically determined distribution models

14	Apr. 8 – Apr. 12	Probability papers, and testing goodness-of-fitness of distribution models.	[1] Ch.7, [3] Ch.4, [4] Ch.4

Error, uncertainty analysis, and optimization

15	Apr. 15 – Apr. 19	Types of uncertainty, sources of uncertainty, analysis of errors, and optimization methods	[2] Ch. 10, [3] Ch. 17, [4] Ch. 6, Appendix, [6] Ch. 2

Final examination period

16	Apr. 24 – May 1	Comprehensive examination.

Course learning outcomes:

Students completing the course should be able to:

1. Make or support optimal decisions by evaluating probabilities and benefits.
2. Compare infrastructure design or improvement alternatives under uncertainty.
3. Model natural hazard phenomena with joint and extreme value probability distributions, calculate their moments, and explore functions of random variables.
4. Identify types of uncertainty and sources of uncertainty in infrastructure systems.
5. Perform analysis and quantification of errors in infrastructure performance prediction.
6. Identify, classify, model, assess and report in writing typical urban system risks.

Reading material:

[1] Ang, Alfredo H.-S., and Wilson H. Tang, (2006). *Probability concepts in engineering – Emphasis on applications to civil and environmental engineering*. 2nd Ed. New Jersey: John Wiley & Sons, Inc.

[2] Singh, Vijay, Sharad Jain, and Aditya Tyagi, (2007). *Risk and Reliability analysis – A handbook for Civil and Environmental Engineers*. American Society of Civil Engineers (ASCE) Press.

[3] Bedford, Tim, and Roger Cooke, (2001). *Probabilistic Risk Analysis – Foundations and Methods*. Cambridge: Cambridge University Press.

[4] Haimes, Yacov Y., (2004). *Risk modeling, assessment and prediction*. 2nd Ed. Hoboken, New Jersey: John Wiley & Sons, Inc.
[5] Parmigiani, G., and L. Inoue, (2009). *Decision Theory – Principles and Approaches*. 1st Ed. Padstow, UK: John Wiley & Sons, Inc.
[6] Melchers, Robert E., (1999). *Structural reliability analysis and prediction*. 2nd Ed. Chichester: John Wiley & Sons, Inc.

On-line resources:

Course material shared via Owlspace and OwlSocrates:
- http://owlspace.rice.edu/
- http://owlsocrates.rice.edu/

Relevant scientific journals:
- Journal of Behavioral Decision Making
- Journal of Multicriteria Decision Analysis
- Journal of Risk and Uncertainty
- Reliability Engineering and System Safety
- Risk Analysis

Course grading:

Homework	20%
Examination I	25%
Examination II	25%
Final examination	30%

Academic honor code:

The Honor System embodies the concept of personal honor in a framework of law and practice. To quote the Constitution, Rice students are placed on their honor by the group "not to violate the trust placed in them in any way."

The result is a system of conducting examinations, writing papers, and performing other academic endeavors with regard for individual honor and without faculty proctoring. Thus, the responsibility for maintaining the validity of academic work is placed on all students.
Website: http://honor.rice.edu/

Disabilities:

Any student with a documented disability needing academic adjustments or accommodations is requested to speak with me during the first two weeks of class. All discussions will remain confidential. Students with disabilities will need to also contact Disability Support Services in the Ley Student Center.

Office hours:

Wednesdays from 3:00 PM – 5:00 PM (Ryon Laboratory, Room 212).